The Equalizer Remote-Control System

By R. E. ANDERSON and C. R. CRUE

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The equalizer remote-control system performs the role of a master control for the adjustable equalizers in the lines of an L-4 system. A control center located at an attended main station repeater may have jurisdiction over several hundred equalizers, some of which may be as distant as 300 miles. The required equalizer adjustments are determined from the relative powers of signals received from remotely controlled test oscillators at the equalizing locations. When necessary, the equalizers are remotely adjusted in discrete steps by means of commands sent out by the control center. Memory circuits associated with the equalizer networks maintain the network gain settings between adjustments. At each distant main station in a control system, a loop-back unit provides decoding and switching that control equalizers at the location and complete far-end looping paths to the lines to be equalized or checked. The looping paths pass the commands used to address the equalizing repeaters, which are located between the main station repeaters. The control system also comprises part of a fault-location scheme, which includes a monitoring oscillator at each repeater.

I. INTRODUCTION

The equalizer remote-control system has been developed and incorporated into the L-4 carrier system as part of an over-all plan for providing in-service equalization capability. Reference 2 describes the controllable transmission elements, which are step-adjustable equalizers with associated solid-state logic and memory circuits. The equalization control technique is based on measurements of the relative powers from test oscillators when they are successively and remotely connected to the inputs and outputs of the equalizers. Disparities in the relative received powers from different points reveal line misalignment and equalizer settings at the test-oscillator frequencies.

The L-4 control system always consists of a sending and a receiving circuit located at an attended main station repeater and a loop-back circuit at each of one or more remote main stations. The remote locations may be either attended or unattended. All commands orig-

inate in the sending circuit; the test signals from the various remote locations are measured in the receiving circuit. The sending and receiving circuits are enclosed in a three-bay console (Fig. 1); the complete assembly is called a control center. The loop-back circuits perform switching and control operations at the remote main stations upon commands from a control center.

The L-4 system also has a built-in fault-location facility for remotely identifying a defective repeater in a line. It consists of a monitoring oscillator at each repeater, and circuits in the control center for remotely turning on groups of the monitoring oscillators and observing the received signals from them.

II. CONTROL SYSTEM PLAN

2.1 *General*

The simplified block diagram in Fig. 2 shows the overall L-4 remote-control system plan and associated nomenclature. In a one-section control arrangement, the adjacent main station repeaters are

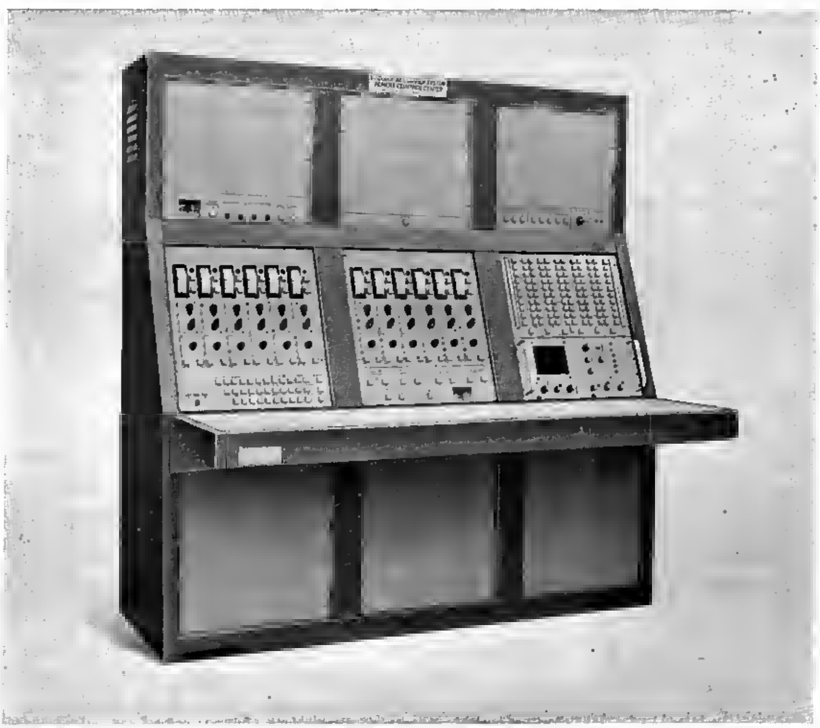

Fig. 1 — Control center.

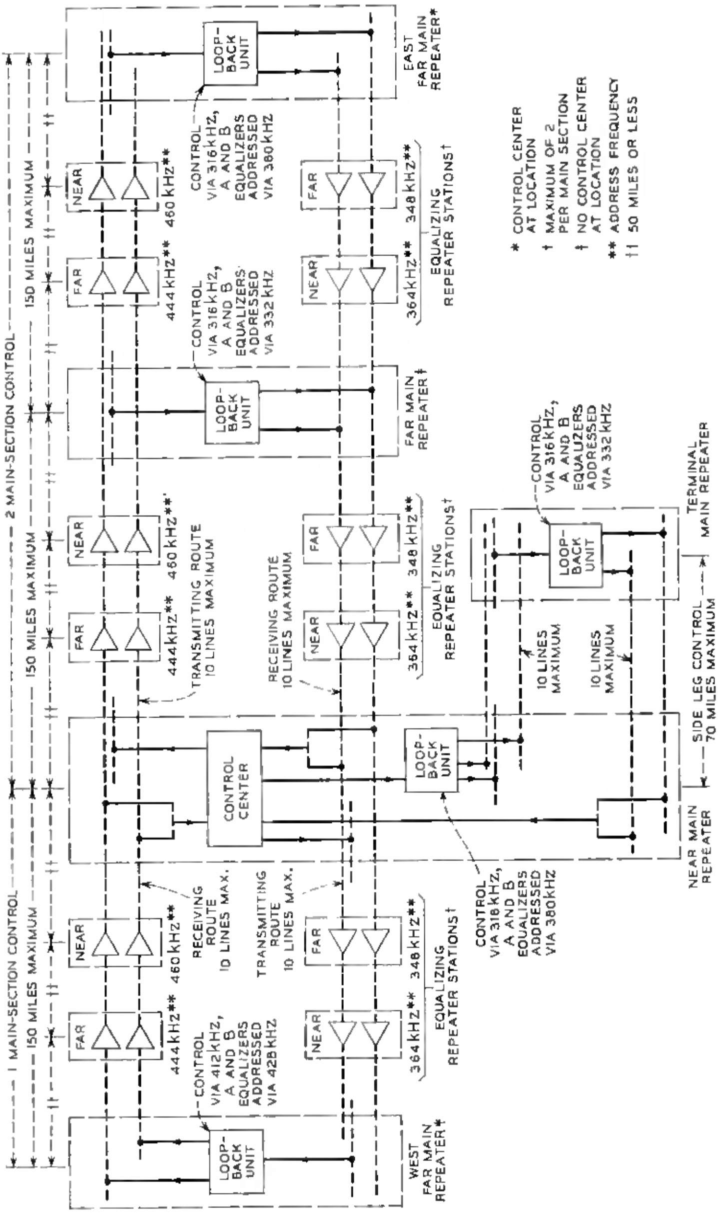

Fig. 2 — Control system—simplified overall plan.

attended and equipped with control centers. In a two-section arrangement, the intermediate main station has no control center, nor blocking, dropping, or branching circuits; it is located between attended locations, each of which has a control center; and it is generally unattended, or at the most, partially attended. One control center may serve up to ten routes; and as suggested by Fig. 2, these may be one-section, two-section, or side-leg arrangements in any combination.

2.2 *One-Main-Section Control*

In the one-section type of operation, the control center at the originating location is used to initiate commands for control operations at the far main repeater, at the near main repeater (originating location), and at up to two equalizing repeater stations between these two locations. The block diagram in Fig. 2 shows a typical layout with two intermediate equalizing repeater stations. The commands for the distant locations are sent out on a regular transmitting L-4 carrier line in the band of 300 to 500 kHz, which is below the lowest message frequencies. The command signals are applied to the line connecting circuit for the regular line on the office side of the automatic protection switch. In this way, the standby line automatically protects the command channel.

2.3 *Commands, the Language of the Control System*

Different combinations of audio-frequency tones are used for the various commands. These are transmitted to a distant location as double-sideband amplitude modulation of a carrier. Envelope detection is then used at the distant location to recover the basic audio command. For control at the originating main station, the audio command tones are transmitted direct to the appropriate A or B equalizer through office wiring. Tuned vibrating-reed selectors are used in the controlled equipment to recognize the command.[3]

As illustrated in Fig. 2, each remote location is addressed by means of a specific carrier frequency assigned to it. A bandpass filter in the controlled equipment passes the appropriate command carrier and the sidebands conveying the audio information.

Test oscillators, provided at each main repeater station and at each equalizing repeater station, are energized and connected to the line during equalizing. Monitoring oscillators, provided at each repeater, are energized for trouble location.

A continuous audio-frequency command tone must be transmitted to keep either type of oscillator turned on. This fail-safe arrangement

assures that oscillators will not operate indefinitely with no remote-turn-off capability should trouble occur in the command generating or transmission facilities. Inability to turn off a group of oscillators should not damage equipment but might hamper trouble shooting and interfere with normal work in distant main sections. Monitoring signals are blocked at each main repeater having a control center, but equalizer test signals are blocked only at frogging, dropping, and branching points. Under normal conditions, equalizing work is scheduled so that an operator does not turn on test signals if they would interfere with measurements in another section down the line.

With the present facilities, every command other than those for oscillator turn-on is a burst of approximately 300 milli-seconds. Most consist of a combination of two audio tones. Three tones are the maximum used for any command.

2.4 *Command Carrier Assignment—One-Main-Section Control*

In a typical one-section control system, the west control center generates command carriers in the 300 to 400 kHz band to equalize lines receiving from the east. The east control center (Fig. 2) uses command carriers in the 400 to 500 kHz band to equalize lines receiving from the west. This arrangement provides needed diversity in the command channel frequencies for the equalizing repeaters in the regular line used as a command channel to the distant main repeater. All command carriers are blocked at the adjacent main station to prevent undesired control of distant line sections.

The east control center operates the loop-back unit at the west main station by means of commands transmitted on the 412 kHz carrier. The 428 kHz carrier is used to address the equalizers at that location. After the loop-back unit receives appropriate commands, it routes the 444 and 460 kHz carriers to a desired line for addressing the far- and near-equalizing repeaters. Figure 2 shows all of the command carrier assignments for controlling the eastward transmitting lines and most of the assignments for the westward transmitting lines.

When two equalizing repeaters occur in a main section, the near and far classifications are determined by the direction of transmission and control (Fig. 2). When there is only one equalizing repeater, it is classified as a near-equalizing repeater. More detailed descriptions of the control center and loop-back units are given in later sections.

2.5 *Two-Main-Section Control*

Figure 2 also illustrates a typical two-section system in which control may be extended up to approximately 300 miles. Basically, the

loop-back units are similar to those used in a one section system, but a few different features are needed and provided. The command channel frequencies are the same as those used for one-section control, with the exception of those used to address equalizers at the distant attended main station. For example, 380 kHz is used to address the east station instead of 332 kHz as with one section. When control is desired in the near section, the loop-back unit at the unattended location is directed to route commands to the desired line in that section. This loop-back unit also routes commands to the equalizers at the unattended main repeater station. When control is desired in the far section, the loop-back unit at the distant attended main station may be directed to route commands either to equalizers at that location or to desired lines in the far section. As in one-section systems, all command channels are blocked at the attended main stations to prevent undesired control of distant line sections. Also, the upper half of the command band is blocked in the west-to-east lines at the unattended main repeater. The lower half of the command band is blocked in the east-to-west lines. This additional blocking prevents commands that are directed to an equalizing repeater in a far section from simultaneously affecting a similar equalizing repeater in a near section. The pattern of classifying the far and near equalizing repeaters is the same as that for a one-section layout. Figure 2 shows the command-channel frequencies associated with the different locations in the two-section arrangement.

III. SENDING CIRCUITS

3.1 *General Considerations*

The sending circuit, shown in Fig. 3, contains several different individual signal-generating and switching circuits that provide the command originating facilities for the remote control system. Under present arrangements, all commands are initiated manually by operating pushbutton keys associated with some of the switching circuits.

Since high speed is not required in these circuits, miniature relays have been used to advantage in providing economical, noise-immune logic for many of the switching functions. Interlocks have been provided in and among the various individual circuits to prevent generation of false or ambiguous commands and undesired lockups in distant associated loop-back units. In several cases, the interlocks have been designed to force the desired sequences of operating the various controls.

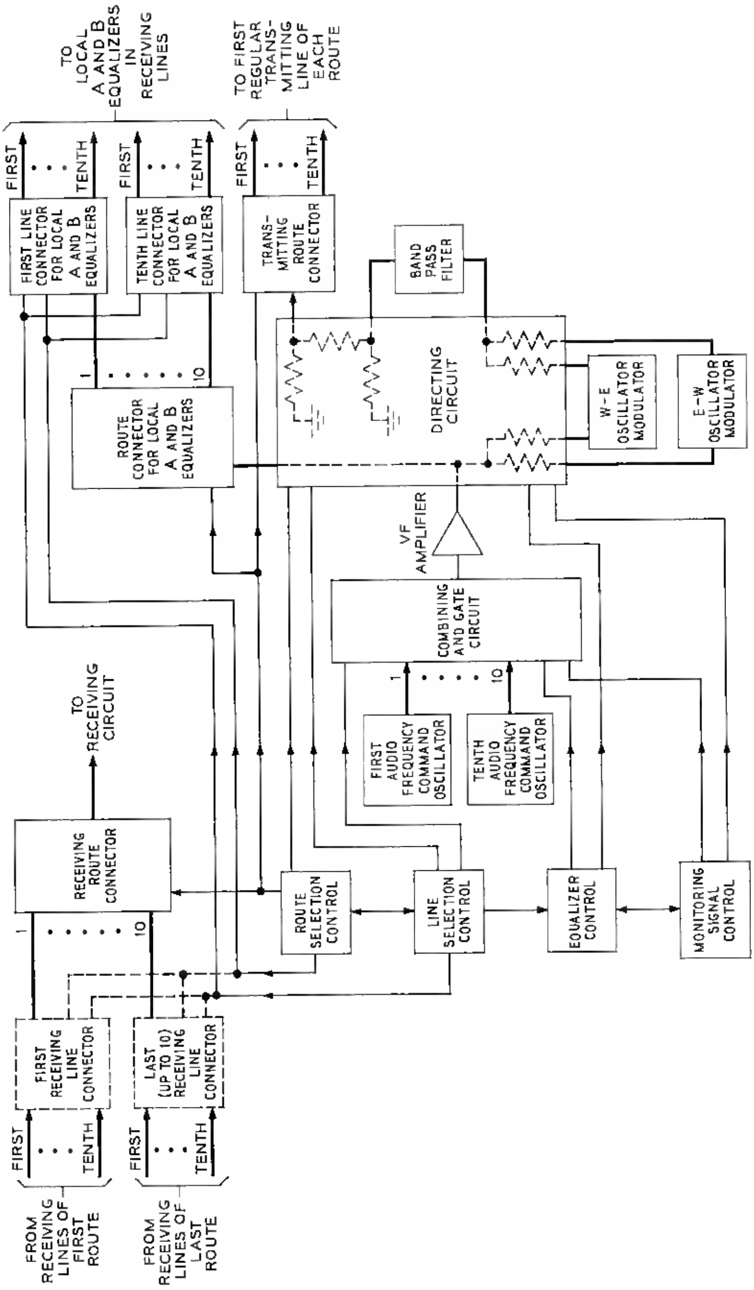

Fig. 3 — Sending circuit block diagram.

3.2 *Route-and Line-Selection Control Circuits*

Route and line selection control circuits are pushbutton-operated switching circuits which use relay and transistor logic to initiate connections to one line section at a time for measurements, equalization, and trouble shooting. The route-selection circuit first selects the desired route; then the line-selection circuit effects connections to a desired line in the chosen route. In one-section operation, the first command addressed to the distant loop-back unit makes the control-system connections to a line at the distant main station. In two-section operation, a choice must first be made between near- or far-section operation. A command initiated by the line selection circuit sets the loop-back unit at the unattended main repeater station for either near- or far-section control. Then the line-selection circuit initiates a line-selection command that is effective in the chosen section.

These circuits also operate the receiving line connecting circuits, which normally associate the receiving facilities of the control center with the line that is receiving command signals. An override control in the line selection circuit provides the means of switching the receiving facilities to a different line of the route. This feature is useful during trouble location and during equalization of out-of-service regular lines in a far main section of two-section control.

Transistor-relay interlocks in the route- and line-selection control circuits prevent the simultaneous selection of two or more lines. The interlocks also preclude releasing or changing a route selection while a line is selected. This prevents leaving operated relays in an idle loop-back unit for an indefinite period.

The line-selection circuit initiates only remote-control commands, namely, those in which the audio commands are conveyed to the controlled point as amplitude modulation of a carrier. A transistor timer determines the command duration. The W-E or E-W oscillator modulator generates the carrier; the audio command oscillators provide the audio tones (Fig. 3). These oscillators, described in sections 3.5 and 3.9, also generate the signals for all other commands that are initiated by the other sending circuits to be discussed. Route selection does not initiate any commands for transmission to a distant location.

3.3 *Equalizer Control Circuit*

After a line has been selected, the equalizer control circuit is operated next, if the equalization is to be checked or adjusted. This pushbutton-operated circuit contains three principal sections of relay and transistor logic. The location-selection part controls the com-

mands that turn on the equalizer test oscillators at various locations; the A or B equalizer selection part initiates the commands and switching for routing subsequent command signals to either the A or B equalizers at the main repeaters; and the equalizer control part initiates the commands for adjusting the equalizer networks.

The location selection or oscillator turn-on command is continuous, whereas a signal burst is used for A or B equalizer selection and equalizer adjustment. Transistor timers set the burst durations. Two different commands are associated witb each equalizer network. One increases the gain and the other decreases it. The audio-frequency command tones are transmitted to a remote equalizer as amplitude modulation of a carrier, whose frequency has been assigned to address the location (Fig. 2). The command tones are transmitted directly to the local equalizers through office wiring from the line connectors for local A and B equalizers (Fig. 3).

3.4 *Monitoring Signal Control Circuit*

The monitoring signal control circuit is part of the remote-fault-location facility for the L-4 system. It contains relay-transistor logic and is pushbutton-operated to originate the commands for turning on monitoring oscillators, which are used to identify a faulty repeater from a control center location. Section VII describes tbe circuit and its relations with other parts of the control system.

3.5 *Audio-Frequency Command Oscillators*

Ten separate plug-in transistor oscillators, originally developed for the *Bellboy®* personal signaling service, provide the audio tones for the various remote-control commands. The oscillators are identical except for a plug-in crystal, which determines the frequency of each. The oscillators operate continuously and are switched in as required by the different sending circuits.

3.6 *Combining and Gate Circuit*

Various combinations of interconnected diode gates provide the means of selecting single tones or combinations of two or three tones from a group of ten for use as remote command signals. Wben there is no command signal being transmitted, the gates are reverse biased; and the transmission paths for tones are blocked or switched off. During a command, one of the previously described control circuits forward biases a group of gates. This action completes a transmission path from one, two, or three of the audio oscillators.

3.7 *Number of Audio Commands*

The combining and gate circuit provides tone-selection gating for 62 different audio commands. The present control system uses only 52 of these; the other ten are available if more commands are needed for future uses. The required number of audio commands bas been minimized by using many of them at several locations. Table I lists the quantity of commands assigned to each class of control function.

3.8 *Directing Circuit*

This circuit, consisting of miniature relays and resistive pads, has three principal functions. First, it routes the audio commands to the oscillator modulators for remote control or to the route connector for local A and B equalizer control at the originating location. Second, it routes keying signals from the originating control circuits eitber to the W-E or to the E-W oscillator modulator, depending on the transmitting direction of the system route being observed. Third, the circuit provides a simple key-operated relay circuit for disconnecting an attenuator pad from the outgoing path for command signals. Under normal operation, the pad remains in the patb. If the command channel gain is abnormally low because of gross misalignment, the pad may be switched out by operating a pushbutton to increase the power of the transmitted command signal about 15 dB.

Table I—Assignment of Commands

Quantity	Function
26	Control of distant loop-back operations, such as looping command transmission path to a desired line and routing equalizer adjust commands to A or B equalizers.
2	Control test oscillators associated with *A* or *B* equalizers.
2	Monitoring oscillator control.
1	Terminate two inputs on command-tone combining network during one-tone command.
12	Adjust *A* equalizer networks and first six B equalizer networks.
8	Adjust last four B equalizer networks.
1	Reset all networks in an A or B equalizer to midrange.
10	Unassigned.
62	

3.9 *Oscillator Modulator and Bandpass Filter*

Each oscillator modulator generates one double-sideband, amplitude-modulated signal at a time for use as a remote control command. There are two versions of this unit; one of each is used in each control center. Six different carrier frequencies, spaced at 16 kHz intervals, are available in each oscillator modulator. Under present arrangements, one available carrier from each oscillator is unassigned. As illustrated in Fig. 2, one oscillator modulator is needed for transmitting control signals in one direction; the other is needed for the opposite direction. The carriers generated in this circuit are crystal controlled and modulated by tones from the audio-frequency command oscillators.

The band-pass filter at the output of the modulator passes signals in the frequency band from approximately 300 to 500 kHz and attenuates signals outside of those limits. This filter assures that harmonics from the command carrier oscillators are suppressed sufficiently throughout the message bands on a working L-4 system.

3.10 *Route and Line Connectors*

The route and line connectors are identical 1 × 10 switching units, each containing 10 miniature wire-spring relays enclosed in individually shielded compartments. The transmitting route connector has one input port, which may be connected to any one of ten output ports. It switches the remote control command signals to an outgoing regular line in an L-4 system route when so directed by the route selection control circuit (Fig. 3).

Transmission is in the opposite direction through the receiving route connector and the receiving line connectors; these units therefore have ten input ports and one output. The receiving route connector switches the output of any one of up to ten receiving line connectors to the receiving circuit in the control center. The receiving route connector is also under control of the route selection control circuit; it operates simultaneously with the transmitting unit. One receiving line connector is associated with each route to switch the output of any one of up to ten L-4 lines to an assigned input on the receiving route connector. The receiving line connector is under control of both the route-selection and the line-selection control circuits.

3.11 *Route and Line Connectors for Local A and B Equalizers*

The route and line connectors for local A and B equalizers are identical 1 × 10 switching units, each with ten miniature relays assembled

on an unshielded printed wiring board. A control center contains one route connector and ten line connectors (Fig. 3). In conjunction with the directing circuit, these units switch audio command tones to the local A and B equalizers in the receiving lines. Each line connector is dedicated to an assigned L-4 system route. These units are operated by the route-selection and the line-selection control circuits, whose interlocks prevent sending command tones to more than one local equalizer at a time.

IV. RECEIVING SECTION

4.1 *Receiving Circuit*

The receiving circuit, shown in Fig. 4, provides: (*i*) adjustable attenuators and indicating meters for measuring A and B equalizer test tones during equalization, (*ii*) a band-pass filter and spectrum analyzer for selecting and displaying received monitoring oscillator tones for fault location, (*iii*) test jacks providing access to the entire received L-4 spectrum and the monitoring tone band.

4.2 *Receiving Amplifiers*

The equalizer tones received from the incoming L-4 lines must be amplified considerably to obtain enough power to deflect indicating meters during measurements and adjustments. Amplifiers of the design used throughout the line connecting and MMX-2 circuits provide the gain needed. In order to minimize the required number of amplifiers, the combined equalizer tones are amplified as much as possible before they are finally separated and amplified individually to drive the indicating meters. In this way, the gain needed in the ten separate tone paths is minimal.

The incoming composite signal must be preamplified to prevent the tone amplitudes from approaching the noise threshold too closely at the input of the first amplifier following the combining network. The two input amplifiers perform this function. The incoming signal contains not only equalizer test tones but also message signals, pilots, and signaling tones. These latter three contribute more energy to the over-all signal than the equalizer test tones and therefore are the controlling factors in establishing the transmission level at the output of the last amplifier in the input group. This level limits the amount of amplification that can be applied to the composite signal as received from a line.

The test tones are separated from the other line signals in the first

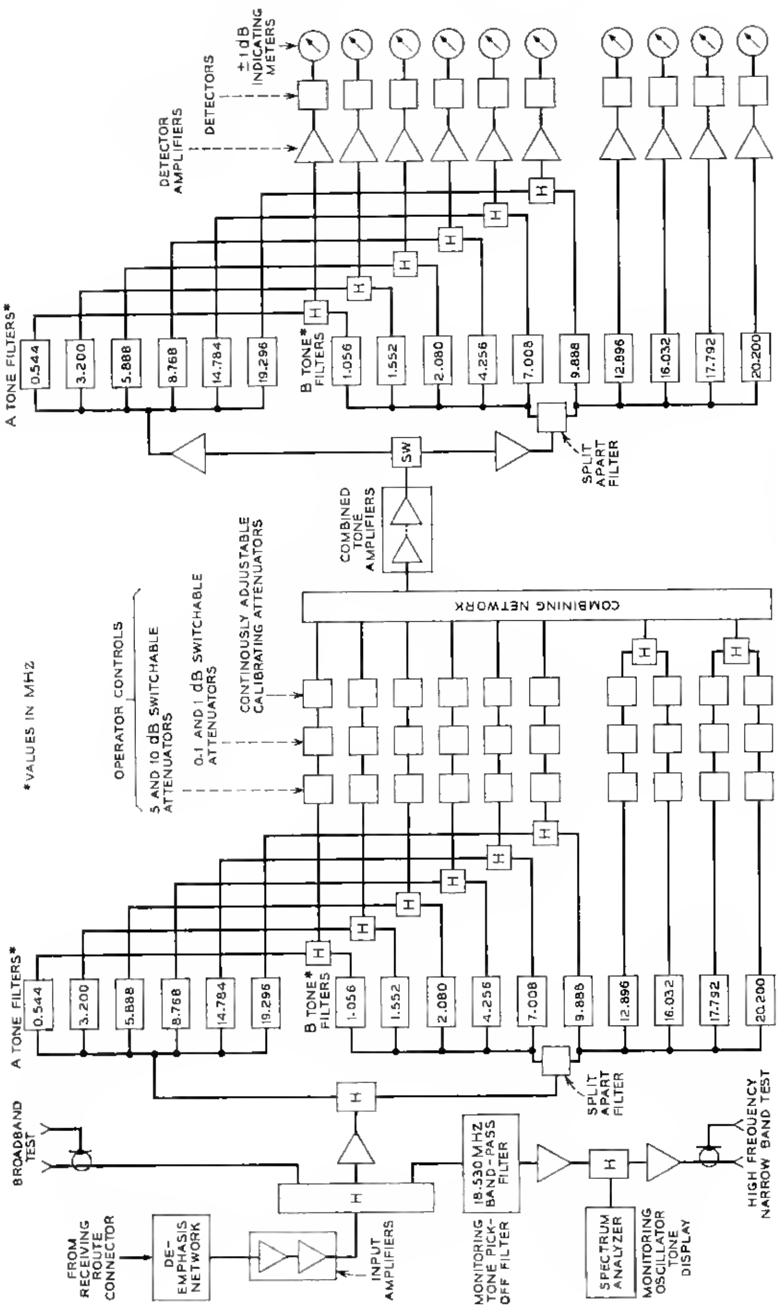

Fig. 4 — Receiving circuit block diagram.

set of crystal band-pass filters. They then pass through adjustahle attenuators and are recombined in a resistive network. The new composite signal, consisting of either six A tones or ten B tones, is then passed through a series of tandem-connected amplifiers. This arrangement permits raising tbe individual tone power much more with combined-tone amplification tban would be possible if the other higher energy line signals were also present.

4.3 *Test Signal Power*

The receiving circuit provides a nominal 71 dB of gain to the A and B equalizer test tones. Under this condition, a tone with a power of approximately -63 dBm at the output of the de-emphasis network causes the corresponding detector meter to read zero dB. When the receiving line is not equalized, tbe test tone power deviates from -63 dBm. Adjustahle attenuators witb a range of ± 11 dB are provided so that eacb tone amplitude can be adjusted to null the indicating meters prior to gain measurements. Additional calibrated step attenuators, having a range of ± 5.5 dB in 0.1 dB steps, are used to measure the A and B test signal amplitudes. Tbe indicating meters are calibrated in 0.1 dB increments and bave a total range of ± 1 dB. The meters are protected so that they are not damaged when the ± 1 dB range is exceeded.

V. LOOP-BACK UNITS

5.1 *General Description*

A control system always includes a control center and one or more loop-hack units, each located at different main stations. All commands transmitted from the control center, except those to equalizers in the same office or to junction loop-hack units for side-leg routes, are received hy a loop-hack unit at a distant main station. The loop-hack unit responds to the commands to make a looped connection to transmitting lines for control of A equalizers located at equalizing repeater sites between main stations, or makes direct connections to A and B equalizers within the main station. In addition, loop-back units at attended main stations comprise part of a far-end near-end interlock for control of monitoring oscillators.

5.2 *Main-Station Equalizer Control*

The loop-hack units provide common equipment for controlling the equalizers in the main station so that command receiving equipment

is not required in each equalizer as at equalizing repeater sites. Connection to the desired equalizer is through miniature relays, which are operated by commands from the distant control center. With this arrangement, a single command receiver can serve up to ten A and ten B equalizers at an attended main station and up to twice as many at an unattended main station. Half of the unattended equalizers are part of the receiving line equipment in the far section of the control system, and half are part of the transmitting line equipment in the near section.

All main station A and B equalizers are controlled by audio-frequency command tones from either a control center or a loop-back unit. Thus, all main station equalizers are alike for both local and remote control. This facilitates maintenance and administration of the equalizers.

5.3 *Loop-Back Unit Types*

There are several types of loop-back units. The particular one installed at a main station depends upon whether the main station is unattended, attended with one- or two-section control, or is part of a side-leg route. Figs. 5 and 6 are block diagrams of two loop-back units. Fig. 5 is a loop-back unit for an unattended main station, and Fig. 6 is for an attended main station where control extends over two main sections. These are the units required in the two-main-section control system illustrated in Fig. 2.

5.4 *Input Amplifiers and Hybrid Network*

The input amplifiers receive the signals at a very low level from the output of the automatic switch for the first operating line and raise the signal amplitude as required for proper operation of the individual loop-back circuits. The amplifiers are broadband and are the same type as used in the control center receiving circuit and elsewhere in the L-4 system. The hybrid network splits the incoming signal path to connect to the individual loop-back circuits.

5.5 *Equalizer and Control Command Receivers*

The equalizer and control command receivers demodulate the equalizer and control command carrier frequencies. The circuits are the same as those in the command receiver located in the line equalizing repeater.[2] Each command receiver contains a narrow band-pass filter, which removes all message and tones from the composite received signal and passes only the appropriate command carrier and

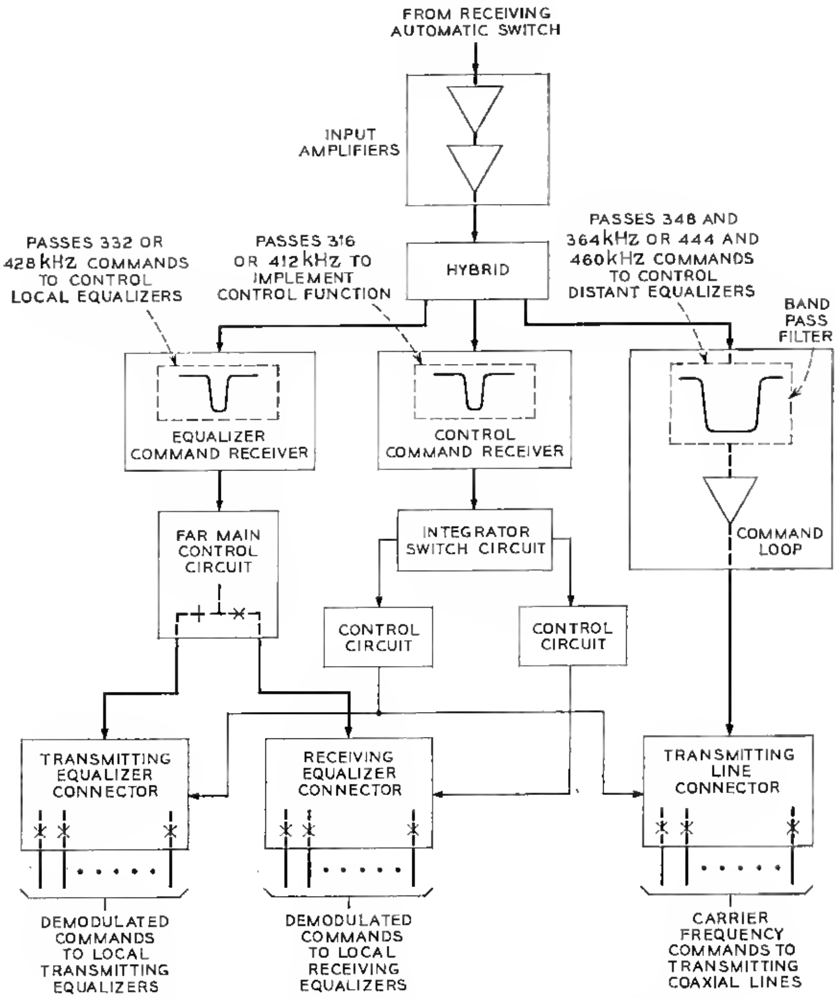

Fig. 5 — Loop-back circuit for unattended main station.

sidebands. The carrier frequency is amplified and detected so that the audio-frequency command tones are obtained at the output.

The command receivers have a gain of approximately 60 dB so that the audio-frequency commands at the output have sufficient amplitude to drive tuned vibrating reed selectors used to separate the command tones.

5.6 *Integrator Switch Circuit*

The integrator switch circuit receives command signals from the control command receiver as bursts of audio-frequency tones, separates the individual tones by means of vibrating reed selectors, and converts them into dc pulses with transistor gates. Most control commands consist of a combination of two audio tones so that two con-

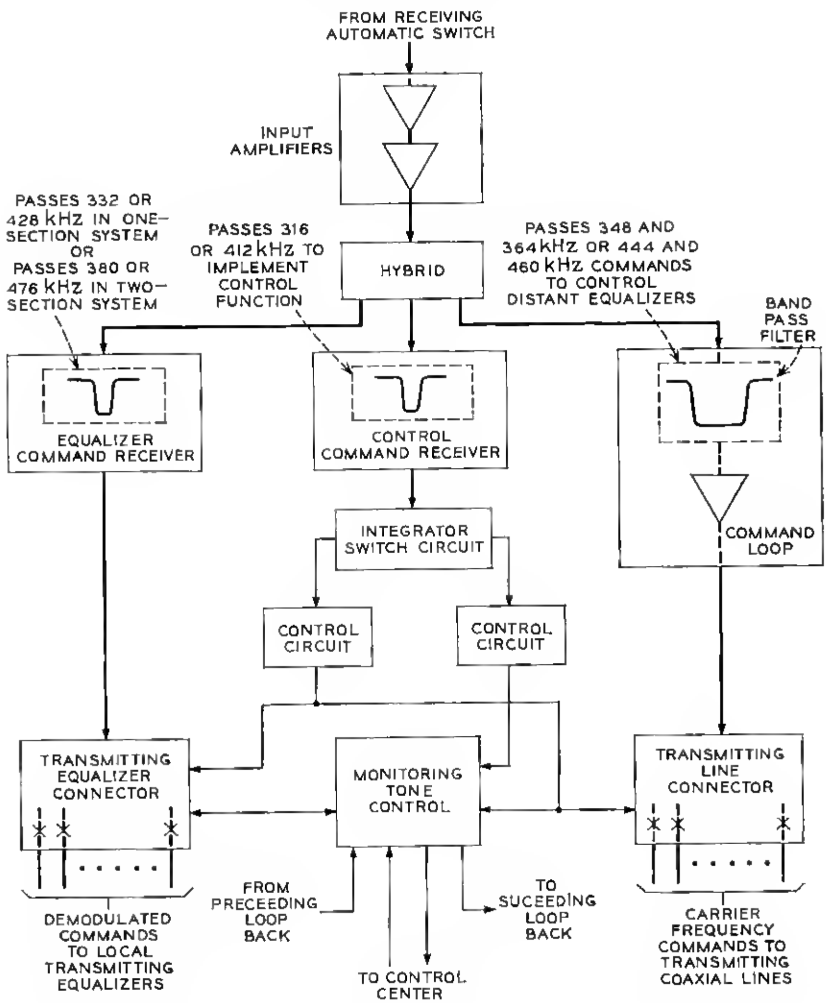

Fig. 6 — Loop-back circuit for attended main station (two main-section control).

current dc pulses are obtained. The duration of the pulses is approximately the same as the duration of tone burst.

5.7 *Control Circuit*

Control circuits respond to dc pulse combinations from the integrator switch circuit to implement line and A or B equalizer connections. In addition, at attended main stations where control centers are present, the control circuit comprises part of the far-end near-end monitoring oscillator interlock between the local control center and the loop-back circuit.

Loop-back units, which are part of control systems extending over two main sections, have two control circuits. One is associated with near-section control functions and the other with the far section. For instance, in the loop-back unit for the unattended main station (Fig. 5), the control circuit at the left operates the line and transmitting AB equalizer connectors, both of which are part of the near section in the control system. The control circuit at the right responds to far-section commands for control of the receiving A and B equalizers.

Conversely, in the loop-back circuit for the attended main station (Fig. 6), the control circuit at the left responds to far-section commands, while the one at the right responds only to near-section line-select commands for inhibiting monitoring oscillator control.

All of the control circuits are identical, and they respond to near- or far-section commands, depending on how they are connected to the integrator switch circuit. The circuit bas logic in the form of transistor gates and provides memory by a relay lockup.

5.8 *AB Equalizer Connector*

The AB equalizer connector makes the connection between local A and B equalizers and the equalizer command receiver. There are transmitting and receiving AB equalizer connectors in loopback units for unattended and side-leg terminal main stations. The transmitting and receiving circuits are identical. The transmitting unit makes connections to local A and B equalizers transmitting away from tbe main station; the receiving unit connects to the equalizers in the receiving lines.

The circuit is comprised of miniature relays which make the connections between the equalizer command receiver, the equalizers, and an AB select circuit. The AB select circuit is a relay transfer switch controlled by transistor gates. The gates are operated in response to A or B equalizer select commands.

Operation of the circuit is such that, normally, connection is made to the A equalizer in the selected line. If it is desired to send commands to a B equalizer, operation of the B select key at the distant control center generates a control command that results in operation of the AB transfer relay. The relay locks up, and the B equalizer remains connected until the A equalizer in that line is selected, or until the line is released or a new line selected.

5.9 *Command Loop*

Commands being transmitted to equalizing repeater sites between main stations are connected to the transmitting line through the command loop, which includes the command band-pass filter and loop amplifier. The command band-pass filter blocks all of the undesired command carrier frequencies and message. The loop amplifier provides gain so that commands are connected to the transmitting lines at the desired power. The transmitting line connector is comprised of wire spring relays which connect the command loop to the desired coaxial line. The transmitting line connector also has one input port which can be connected to any of ten output ports upon command from the distant control center.

5.10 *Far-Main Control Circuit*

The far-main control circuit is required in those loop-back units that are connected to A and B equalizers in both the transmitting and receiving lines in the main station. The far-main control circuit connects the output of the equalizer command receiver either to the receiving or to the transmitting AB equalizer connectors. It consists of a transfer relay controlled by transistor gates and is similar to the AB select circuit in the AB equalizer connectors. Near-section, far-section control commands from the control center operate the gates to control the relay. Normally, the relay is released and connection is made to the transmitting AB equalizer connector. When control is exercised over far-section equalizers, the relay is locked up. It is released when the near-section is selected or lines are released at the control center.

5.11 *Monitoring Tone Control Circuit*

The monitoring tone control circuit is part of the far-end near-end interlock for control of monitoring oscillators. This circuit is required in loop-back units at attended main stations where there are control centers. It consists primarily of an inhibit circuit interconnected with

line-select relays in the AB equalizer control circuit.

The inhibit circuit includes transistor logic operated by signals from the integrator switch circuit and a timer. The gates and timer control an inhibit relay, which is part of the monitoring oscillator control interlock with the control center. The overall monitoring oscillator control arrangement is described in following sections on fault location and the far-end near-end interlock.

VI. EQUALIZER ADJUSTMENT

6.1 *General Discussion*

Adjustable networks in the A and B equalizers function in specified frequency bands to minimize the system gain deviations remaining after operation of the regulating repeaters.[2] The A equalizers provide the initial, relatively coarse, gain bump corrections; the B equalizers follow with the final, comparatively finer, bump corrections.

The set of test frequency oscillators associated with the equalizer networks in any given equalizer produces the same output power (within 0.15 dB) and frequencies as those in any other equalizer. This permits gain deviation measurements between any two points in terms of the difference in measured power from the two points.

Interruption of dc power to an equalizer causes the settings of the memory elements to be lost, and random settings appear when power is restored. To expedite re-equalization, random memory settings can be cleared and all of the gain shapes reset to their midrange positions by means of a single command from the control center.

6.2 *Theory of Equalizer Adjustment*

Figure 7(a) shows the A equalizers in one main section, which may be up to 150 miles long. The location designations for the equalizers are:

FM—far main repeater,
FE—far equalizing repeater,
NE—near equalizing repeater,
NM—near main repeater.

These designations are the same as those used on the equalizer selection and control panel of the control center. The panel is part of the equalizer control circuit discussed in Section 3.3.

The test-frequency oscillators, shown symbolically in Fig. 7, are outside of the equalizers to indicate that their outputs can be switched

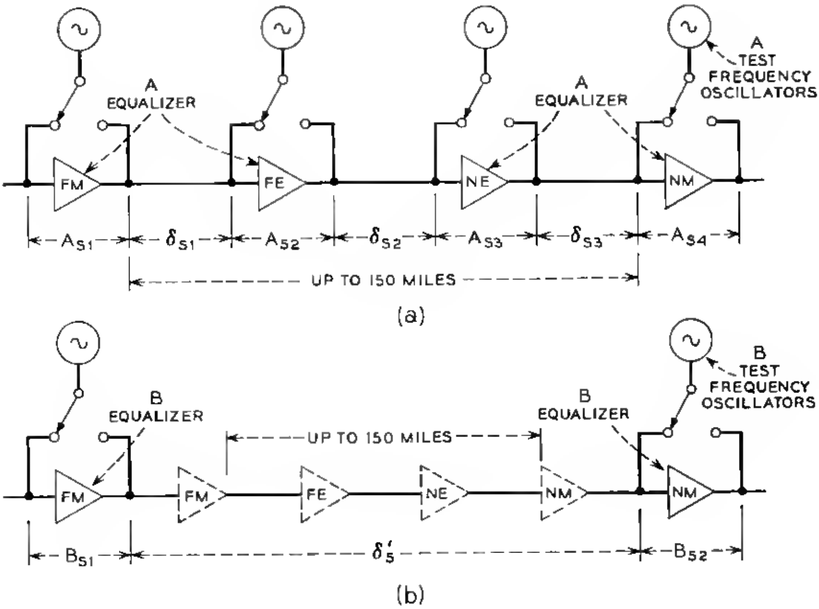

Fig. 7 — (a) A equalization; (b) B equalization.

either to the input or output. This is accomplished by operating appropriate keys on the control panel.

Figure 7(b) shows the B equalizers located at the two main stations. The test-frequency oscillators for these equalizers are also controlled by keys on the equalizer selection and control panel. The following definitions, as indicated in Fig. 7(a), will be used to describe the A-equalization procedure.

$A_{s\ell}$ = A equalizer gain setting at the test frequency associated with the Sth adjustable equalizer network at the ℓth equalizer.

δ_{sk} = gain of the kth line section at the Sth test frequency.

Since there are six A equalizer networks, S can be any integer from 1 to 6.

The values of δ_{sk}, as they deviate from zero, represent line section misalignment, which is corrected for by making compensating changes in the equalizer gain setting $A_{s\ell}$. The gain of the section at a particular test frequency may be expressed as

$$M_{SA} = A_{S1} + \delta_{S1} + A_{S2} + \delta_{S2} + A_{S3} + \delta_{S3} + A_{S4} . \qquad (1)$$

As discussed in Ref. 2, pre- and postequalization are used for each line section to minimize modulation and noise penalties on the system performance; thus each equalizer corrects for one half of the deviation in the adjacent line sections.

Therefore, (1) can be conveniently rearranged as

$$M_{SA} = \left[A_{S1} + \frac{\delta_{S1}}{2}\right] + \left[\frac{\delta_{S1}}{2} + A_{S2} + \frac{\delta_{S2}}{2}\right] + \left[\frac{\delta_{S2}}{2} + A_{S3} + \frac{\delta_{S3}}{2}\right] + \left[A_{S4} + \frac{\delta_{S3}}{2}\right]. \tag{2}$$

When the equalizers are properly set, each bracketed term in (2) is zero; and the section misalignment, M_{SA}, is zero. If the main section equalized, the required changes in equalizer gains are

$$\begin{aligned}
\Delta A_{S1} &= -\left[A_{S1} + \frac{\delta_{S1}}{2}\right] \\
\Delta A_{S2} &= -\left[A_{S2} + \frac{\delta_{S1} + \delta_{S2}}{2}\right] \\
\Delta A_{S3} &= -\left[A_{S3} + \frac{\delta_{S2} + \delta_{S3}}{2}\right] \\
\Delta A_{S4} &= -\left[A_{S4} + \frac{\delta_{S3}}{2}\right].
\end{aligned} \tag{3}$$

The gain changes are implemented by transmitting equalizer adjust commands to the several equalizers. The gain corrections given by (3) can be translated into the number of commands required to effect the correction. Let

k_A = change in A equalizer gain per step

and

n_{sl} = number of times the (+) or (−) keys must be depressed for correction of the sth shape at the ℓth location.

Then

$$\begin{aligned}
n_{s1} &= \frac{1}{k_A}\,\Delta A_{s1}\,, \qquad n_{s2} = \frac{1}{k_A}\,\Delta A_{s2} \\
n_{s3} &= \frac{1}{k_A}\,\Delta A_{s3}\,, \qquad n_{s4} = \frac{1}{k_A}\,\Delta A_{s4}\,.
\end{aligned} \tag{4}$$

Normally, the system gain deviation and the values of n_{st} are small. The section misalignment remaining, after A equalization, is removed by B equalization. In Fig. 7(b), the section misalignment to be corrected is defined as δ_s' where

δ_s' = gain deviation at the sth B test frequency.

The B equalizers have ten adjustable networks, so s can be any integer from 1 to 10. The equalizer gains are defined as B_{st} where

B_{st} = B equalizer gain setting at the test frequency associated with the sth adjustable equalizer network at the tth equalizer.

The section misalignment at B test frequencies is then given by

$$M_{sB} = B_{s1} + \delta_s' + B_{s2} \, . \tag{5}$$

As is the case for an A equalization, B_{s1}, B_{s2} and δ_s are obtained by measurements at the B test frequencies; pre- and postequalization are used so that each B equalizer corrects for one half of the line-section misalignment. Hence, the required corrections in the B equalizer gains are

$$\Delta B_{s1} = -\left[B_{s1} + \frac{\delta_s'}{2}\right], \qquad \Delta B_{s2} = -\left[B_{s2} + \frac{\delta_s'}{2}\right]. \tag{6}$$

The required gain corrections can be translated into the number of commands required as

$$n_{s1}' = \frac{1}{k_B} \Delta B_{s1} \, , \qquad n_{s2}' = \frac{1}{k_B} \Delta B_{s2} \, , \tag{7}$$

where k_B is the change in B equalizer gain per step, and n_{s1}' and n_{s2}' represent the number of times the (+) or (−) keys must be depressed to adjust the sth network in the FM and NM B equalizers, respectively.

The values of n_{st} and n_{st}' to correct A and B equalizer gain settings are accurate only to the extent that k_A and k_B are constants. This condition is not precisely met in the equalizers, although for a given gain shape, the k_A and k_B can be assumed constant. k is approximately 0.3 dB for A equalizer gain shapes and 0.2 dB for B equalizer gain shapes. Any resulting errors in equalizer gain can be corrected by touching up the gains of the A and B equalizers at the main stations.

Another factor that must be considered, when applying equalizer corrections, is the interaction between equalizer networks. Since some of the gain shapes overlap, it is required that the adjustments be

made in a sequence that minimizes the interaction effects. In the sequence followed, a group of noninteracting shapes is adjusted first. After tbese sbape cbanges bave stabilized, a second group is adjusted. The shapes in the second group are affected by tbe first but do not react on the first group or each other. Tbis procedure eliminates tbe need for additional measurements and computations or automatic computer networks to correct for the interactions.

The (+) and (−) keys, located to the right of each meter, are used to send commands to adjust the gain shape associated witb tbat section of panel. Each time the (+) key is depressed, the equalizer gain is increased one step.

VII. FAULT-LOCATION SCHEME

7.1 *General Description*

A testing arrangement has heen designed and built into the L-4 system to provide a means of remotely identifying a faulty repeater. The arrangement is also useful for quickly verifying, under apparently normal conditions, that the gains of individual repeaters are in fact approximately normal. Utility of this testing facility is limited during certain kinds of total failures and during the type of transmission impairment, such as excessive intermodulation, in whicb there may not be significant gain abnormality.

As part of the fault-locating equipment, each repeater location contains a monitoring oscillator. Upon command from a control center, one group of these oscillators may be turned on at a time in the lines and routes served by the control center. Power is supplied to the oscillators by the main and equalizing repeater stations.[2] Each group contains about half of the oscillators between adjacent power supply points. For example, a group powered from a main repeater station covers about half of the repeaters leading to the adjacent equalizing repeater. Similarly, the groups on either side of an equalizing repeater cover ahout half of the repeaters in the respective, adjacent line sections.

Eacb oscillator in a group emits 1 of 16 frequencies spaced at 4 kHz intervals between 18.500 and 18.560 MHz. In each group, the frequencies are assigned consecutively to the repeaters to facilitate identification in case of trouble.

Tbe command for turning on a group of monitoring oscillators is

initiated in the monitoring signal control circuit, part of the sending section of the control center (Fig. 3). Any one of up to six groups of oscillators may be selected in a line section by depressing the appropriate pushbutton key on the rightmost sloping front panel of the control center (Fig. 1). Interlocks among this and other circuits in the control center prevent generating a monitoring signal turn-on command until after a route and line have been selected and the equalizer control circuit has been released. The turn-on command is directed to an A equalizer at the location that energizes the group. Logic and switching associated with the A equalizer then complete the power connection.

7.2 *Local Interlock*

The transistor interlock in the monitoring signal control circuit prevents turning on two groups of monitoring oscillators at the same time. If two or more of the six pushbuttons are depressed simultaneously, all of the relays for initiating turn-on commands will remain released until only one is depressed. Control of monitoring oscillators may be released by depressing the release pushbutton, by changing the line selection, or by releasing the line selection.

7.3 *Received Display*

A spectrum analyzer in the control center displays the received monitoring signals as a group of evenly spaced pips. In a normal system, the envelope outlined by the tops of the pips is smooth for oscillators located between regulating repeaters, as shown in Fig. 8. However, there may be a tilt to the display if the cable is not at its annual mean temperature. Under this condition, the regulating repeaters insert gain corrections so that small discontinuities appear at points in the display corresponding to where the regulating repeaters are located. A trouble is indicated by a large amplitude difference in adjacent pips or by missing pips. A photographic record is kept of the normal display for each group of oscillators to facilitate picking out a trouble. If an oscillator should fail, it can be differentiated from a repeater failure since this results in the disappearance of a single pip in an otherwise normal display.

7.4 *Far-End Near-End Interlock for Monitoring Signal Control*

When a group of monitoring oscillators is turned on, monitoring signals are applied to four lines, two in each direction. Interlocks pre-

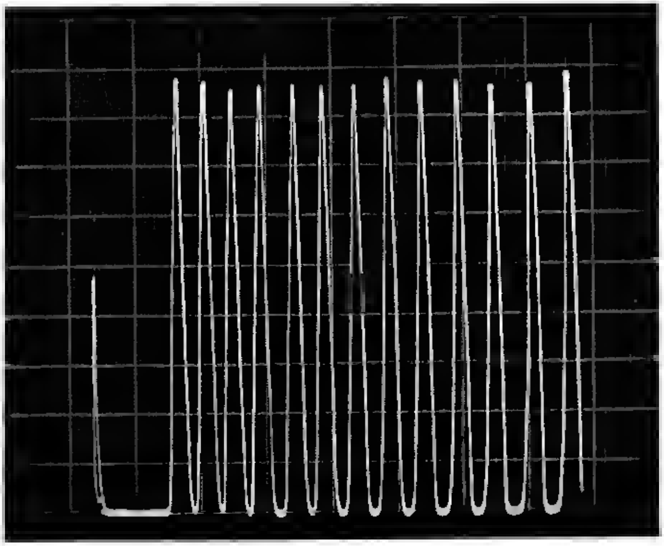

Fig. 8 — Typical spectrum analyzer display of received monitoring tones.

vent the control centers at both ends of a control section from turning on oscillators in the same lines at the same time. This precludes the confusion that would occur if two groups of monitoring oscillators are turned on simultaneously in a line section. The confusion would result because the spectrum analyzer display would include multiple signals at the same nominal frequencies.

Before a command can be transmitted to turn on a group of monitoring oscillators, the conditions imposed by the far-end near-end interlock, as well as those imposed by the local interlocks, must be met. The far-end near-end interlock is arranged between the sending circuit of a control center and the loop-back units at that location. Each of the loop-back units is associated with a different route under jurisdiction of its own distant control center.

Each loop-back unit receives route- and line-select information from the local control center, and monitoring-tone and line-select information from the distant control center. This information is then used in the loop-back units to complete or interrupt a circuit path between the line-select and monitoring-tone control circuits in the control center. When the circuit path is opened, tbe monitoring tone controls associated with the appropriate route and particular pair of lines be-

come inoperative. Under this condition, the operator cannot turn on any group of oscillators on that route and those lines; and lighted lamps indicate that the distant control center operator has turned on monitoring oscillators.

Although the local operator is inhibited on one pair of lines, he can still observe the tone group that has been actuated on these lines by the distant location. He can also turn on and observe monitoring tones in any of the other pairs of lines.

Once inhibited, the local control center can turn on monitoring oscillators only if the attendent at the distant control center does any one of the following: (*i*) turns off monitoring signals, (*ii*) changes line selection, or (*iii*) releases line selection.

VIII. POWER AND FUSING

An operating control center draws about 10 amperes of current from the unregulated 24-volt office battery. Three dc-to-dc converters in the control center console are energized from the office battery to provide regulated sources of 25-volt power for the various control circuits and amplifiers. Some of the front panel indicating lamps operate direct from the office battery. The 24-volt and 25-volt power is distributed to the control circuits through standard alarm-type fuses, which are located in the console.

The spectrum analyzer operates from the office 115-volt, 60-cycle, ac power. The loop-back units are energized from other dc-to-dc converters, also operated from 24-volt office battery. These are located in the control-connecting bay, which is associated with the L-4 line equipment in the main station. A typical operating loop-back unit causes a current drain of about 1.3 amperes on the office battery. Fuses in the control-connecting bay distribute the regulated 25-volt power to the various amplifier and control circuits that form the loop-back unit.

The fuses for both the control center and the loop-backs provide overcurrent protection and the means of removing voltage to the circuits for maintenance. A blown fuse in either of the groups operates an alarm relay, which in turn activates the office alarm system.

IX. EQUIPMENT ARRANGEMENTS

The control center is assembled in an enclosed three-bay console having both vertical and sloping front panels and a full-length writing

shelf (Fig. 1). The sloping front panels contain most of the facilities that are touched or observed by an operator to initiate commands, to make measurements, and to locate remote faults. These front-panel facilities consist of pushbutton keys, indicating lamps, knob-controlled adjustable attenuators, meters, and a spectrum analyzer. Lighted lamps identify the selections of the route, line, equalizing location, and group of turned-on monitoring oscillators. The two meters at the extreme right and the attenuators directly below are spare equipment.

The various control circuits located inside the console are assembled on printed wiring boards. In general, each board is dedicated only to one basic function, such as route or line selection. Local cables provide the connections among the various control boards, and between the boards and the operating keys and lamps on the front panels.

The printed wiring boards are mounted on shelves that are accessible by opening the doors on the back of the console. Those shelves containing active devices and relays are equipped with slides to facilitate quick pull-out for circuit maintenance. The other shelves that contain only passive elements are screwed to the flanges of the uprights. Loops in the local cables permit limited pull-out of the shelves without disconnecting any wires.

In the receiving section of the control center, all transmission circuits except the detectors are shielded. A large terminal block in the console provides readily accessible terminals to which the installer attaches the many leads for control of local A and B equalizers and other leads associated with the receiving line connecting circuits and the loop-back units. A large lead connecting the console framework to the building ground guards against accidental shock to operating personnel.

The loop-back unit is assembled on three fabricated shelves attached to unit mounting bars. The over-all assembly is arranged for mounting on a standard 23-inch relay rack and is located in the control connecting bay of an L-4 bay lineup. The various control circuits are assembled on printed wiring boards, each of which is generally associated with one function such as control of line selection. Interconnections among the boards are made by means of local cables. Partial access is provided to the components on a shelf when it is secured in place. For complete access, mounting screws must be removed and the shelf must be withdrawn. Adequate loops in the local cables permit the withdrawal without disconnecting any leads.

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